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# ON THE INDUCTION APPARATUS.

BY

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IT is now more than twenty years since I discovered the method of making the induction coil, or a coil by which an electric current of enormous intensity may be produced with the aid of a single galvanic cell,—a coil which is now to be used for working the Atlantic Telegraph. Mr. Faraday was the first who developed the laws of electrical induction; but he did not discover the method of making a coil by which a current of very great intensity may be obtained by means of a very small battery. This was first discovered in Maynooth College in 1836. In the summer of 1837, I sent the late Mr. Sturgeon a small coil which he exhibited at a meeting of the Electrical Society in London, and from which he gave shocks to several of the members. After the meeting, I received a letter of thanks from him, in which he described the astonishment of those who experienced the extraordinary power of the coil. This was the first induction coil of great power ever seen outside the College of Maynooth. The first notice of the discovery of the coil is found in a paper of mine published in the London Philosophical Magazine for December 1836. In 1836 and 1837 I also discovered that the intensity of the current induced in the coil increased with the number of cells employed, and that a shock may be got from the coil at the moment of making as well as of breaking connexion with the battery. In April 1837 I published, in Sturgeon's 'Annals of Electricity,' a description of an instrument which I

devised for producing a rapid succession of electrical currents in the coil by rapidly making and breaking communication with the battery. This, as Mr. Bachhoffner says in one of his papers published in Sturgeon's 'Annals,' was the first contact-breaker ever made. Thus, before April 1837 I had completed the coil as a machine for producing a regular supply of electricity. From 1837 till the end of 1854 my attention was directed to other matters. Since the beginning of 1855, I made a long series of experiments on the various parts of the induction coil and apparatus. Although my experiments are not yet finished, I thought it better to lay the results already obtained before the British Association*.

The following are the results of my experiments:—First, a method of getting a shock directly from the armature of a magnet at the moment of its demagnetization; secondly, the discovery of what I believe to be a new fact or law connected with the action of iron on a battery by which it is magnetized, viz. that if iron be put into a coil of covered wire, the ends of which are connected with a battery, the quantity of electricity flowing from the same battery through another coil connected with it will be considerably greater when the first coil is nearly filled with iron than when there is little or no iron in it; thirdly, a form of core which has five advantages over the cores in common use, which will enable us to get intensity and quantity currents, and may therefore answer for the Atlantic Telegraph and for the electric light; fourthly, an improved method of insulating the secondary coil; fifthly, a contact-breaker in which the striking parts are copper, and which acts as well as if they were platina; sixthly, an explanation of the action of the condenser, which appears to me more satisfactory than any other I have seen; lastly, some new facts regarding the condenser, and an improved method of making it.

The first result is a means of obtaining, not from a coil surrounding the armature of a magnet, but from the armature itself, a voltaic current capable of giving a shock. This result is obtained by making a coil of fine insulated iron wire, and an electro-magnet of such a form that the coil will fit between its poles. The iron coil is then the armature of the magnet. If the helix of the electro-magnet be connected with a battery, the iron becomes magnetized; and on account of its proximity to the magnetized iron, the coil of iron wire, or the armature of the electro-magnet, will be also magnetized, and will lose its magnetism when the connexion between the battery and electro-magnet is broken, or

* This paper was read in Section A. (on Mathematics and Physics) at the late meeting of the British Association in Dublin. The paper being hastily written, some things were omitted which are here supplied.

when the electro-magnet is demagnetized. If, at the moment the iron coil loses its magnetism, the ends of it be held in the hands, a shock will be felt. If the ends of the iron coil be connected with a delicate galvanometer, the needle will be deflected at the moment the coil is magnetized by the electro-magnet. Hence at the moment of magnetization or demagnetization, an electric current is produced in each section of the iron at right angles to its magnetic axis. From this, two inferences may be drawn,—first, that if for the copper coils used in magnetic telegraphs, coils of iron wire were substituted, electrical currents of greater intensity might be obtained; secondly, that if iron wire were used in the secondary coil of induction coils, the intensity of the secondary currents would be increased.

Here I shall take occasion to explain the causes which produce the secondary current in the induction coil. I believe that this current is the result of the combined action of three inductive forces; one arising from the sudden cessation or destruction of the magnetism of the core, the second from the cessation of the magnetism of the primary coil, and the third from the destruction of the magnetism of the secondary coil at the moment the connexion between the battery and primary coil is broken. This supposes, first, that as long as the primary coil is connected with the battery, magnetic power is given, not only to the iron core, but also to the primary and secondary coils; and secondly, that in each of them, at the moment of losing its magnetism, an electric current is produced in each of them as well as in all contiguous conductors. Both, I think, may be satisfactorily proved. First, every one knows that the iron core is magnetized by the primary current. Secondly, the primary coil itself is a magnet as long as it is connected with the battery; for every wire or conductor through which a voltaic current flows has magnetic properties: one of its sides will attract the north pole of a magnetic needle, and the opposite will attract the south pole; so that if the wire be placed over the needle at rest, the latter will be deflected from the magnetic meridian. The wire, or conductor of a galvanic current has its magnetic poles, not at its extremities, but at its opposite sides; so that were the wire divided into two halves along its length, one half would be a north and the other a south magnetic pole. The magnetic axis of such a wire is one of its diameters, or a line joining its opposite sides. Thirdly, the secondary coil is a magnet when the primary coil is connected with the battery. This is evident when the secondary coil is made of iron wire; for the primary current magnetizes iron by which it is surrounded as well as iron enclosed within it: it induces in each section of the surrounding as well as of the enclosed iron, an electrical current which magnetizes the iron. I have

found by experiment that iron outside the primary coil is not so strongly magnetized as iron enclosed within it. When, as is commonly the case, the secondary coil is made of copper wire, it is also a magnet; for the primary current induces an electrical current in each spiral of the secondary coil of copper, as well as in each section of the iron core. This current magnetizes each spiral of the copper coil, and makes the whole coil a magnet at the moment the primary coil is connected with the battery. Now we must suppose, that as the primary current, whilst it continues to flow, maintains in the iron core the magnetic power produced by the currents induced in each section of the iron at the moment the primary coil is connected with the battery, although these currents last but an instant, so also the same primary current will maintain in each of the spirals of the copper coil the magnetism given to them by the currents induced in them at the moment the battery connexion is made. There is no reason why the continuance of the primary current should not maintain its first effect in the copper spirals as well as in the iron, since the first effect is the same in both, viz. the magnetization of both. Hence, when the primary wire of an induction coil is connected with a battery, the secondary coil is always a magnet, as well as the core and primary coil; and therefore in every induction coil we have three magnets so long as its primary coil is connected with a voltaic battery; and the three lose their magnetism the moment the battery communication is broken. Now in every magnet, at the moment of the cessation of its magnetism, an electric current is produced in a direction at right angles to the magnetic axis, in the magnet itself and in all contiguous bodies. First, it has been already shown that at the moment iron loses its magnetic power, an electric current is produced in each section of it in a direction perpendicular to its magnetic axis. By the laws of induction, these currents induce parallel ones in every contiguous conductor. Secondly, when a current flowing from a battery through a copper wire ceases, the wire loses its magnetism; and it is found by experiment, that at the moment of losing its magnetism, an opposite electrical current is produced in the whole length of the wire, or in a direction at right angles to its magnetic axis. Hence, because in every induction coil excited by a battery there are three magnets, viz. the core, the primary and secondary coils, having a common axis, and because at the moment the connexion with the battery is broken the three lose their magnetic power, an electrical current is produced in each section of each of the magnets in a direction perpendicular to their common axis; and these currents in each magnet induce electrical currents in the other two. Therefore, when the connexion with the battery is broken, a current is pro-

duced in the secondary coil, which is the result of the combined action of three inductive forces arising from the suspension of the magnetism of the core, of the primary and of the secondary coil. When the secondary coil is made of iron wire, the magnetic power it will receive from the primary current, and from the magnetic inductive force of the core, will be far greater than if it be made of copper wire; and therefore the intensity of the secondary current in a coil of iron wire must be much greater than that of the secondary current in a coil of copper wire. I showed, at the late meeting of the British Association in Dublin, an induction coil in which the secondary wire was of iron: its length was about 21,000 feet, and its thickness about the $\frac{1}{100}$dth of an inch. With a single cell, 6 inches by 4, and without a condenser, this coil gave sparks half an inch long. Should a condenser of the proper size increase the length of the sparks, as it does in Mr. Gassiot's great coil, in a thirtyfold ratio, my coil ought to give sparks 15 inches long with a single cell. I have not yet tried it with a condenser: I made two large condensers, in which, when both were united, the acting surface of each plate exceeded 600 square feet. After being used for some time, the insulation of the plates gave way, and the action of the condenser became feeble, and once ceased altogether. I intend to reconstruct both condensers as soon as possible, and to try their effect on the coil, on which I have, since the meeting of the Association, coiled about 28,000 feet more of fine iron wire, so that at present the length of the secondary coil is nearly 50,000 feet. Since the increased length of wire was put on the coil, I have got from it, with a single cell, 6 inches by 4, and without a condenser, sparks $\frac{15}{16}$ths of an inch in length. I expect that with the same battery it will give sparks at least an inch long without a condenser. This is, I believe, the most powerful coil ever made.

The second result is, that if a bundle of iron wire be put into a coil of insulated thick copper wire connected with a battery, the quantity of electricity which will flow through another coil in contact with the same battery, will be considerably greater when the iron wires are in the first coil than when they are altogether or partly removed. This I found by using a contact-breaker worked by an electro-magnet, the helix of which was connected with the same battery by which an induction coil was excited. In trying the effect of the induction coil without an iron core in its primary coil, I found that the action of the electro-magnet of the contact-breaker was slow and feeble. When a few wires were put into the primary coil, the action of the contact-breaker was sensibly increased; and when the primary coil was filled or nearly filled with wire, the attraction of the electro-magnet became considerably stronger, and consequently

the voltaic current flowing round it must have been considerably increased. Since the core of the induction coil increases the quantity of electricity flowing from the battery through the helix of the electro-magnet, we must suppose that the iron of the magnet reciprocally increases the quantity of electricity transmitted through the primary coil, and that therefore little or no battery power is lost by using an electro-magnet for making and breaking contact, instead of the magnetized core of the coil. Hence it appears also to follow, that a secondary current of greater intensity may be got with a battery of given power from a great number of small coils than from one large one, in which the conducting power of the primary coil is equal to the sum of the conducting powers of the primary wires of all the small coils; for the magnetic power of the core of each of the small coils will be increased by the magnetism of the cores of the others.

The third result is a form of core which has five advantages over all the cores in common use, and which may enable us to get electrical currents having at the same time great intensity and considerable quantity, and may therefore be very useful for working the Atlantic Telegraph, and for producing the electric light. In my experiments on the core, I have used cores of six different forms, and varying in weight from one pound to two hundred and a half of iron wire. I have used, first, a core of uninsulated iron wire coiled on an iron bar; secondly, the ordinary bundle of iron wires; thirdly, an elliptical or flat bundle of wires; fourthly, a coil of covered iron wire; fifthly, a core consisting of a coil of insulated iron wire and of a bundle of iron wire; lastly, a core consisting of two concentric coils of insulated iron wire, one made of fine, the other of thick wire.

When the uninsulated iron wire coiled on a bar of iron was employed as a core, the spark produced by the secondary coil was less in length and brightness than when the iron bar alone was used; because a complete circuit was formed between some of the spirals and those above them, whilst the other spirals were insulated from each other by the oxide of iron on the surface of the wire.

The elliptical or flat bundle of wire receives from a given voltaic current flowing through a primary coil made of wire of given length and thickness, greater magnetic intensity than a cylindrical bundle does; because when the length of the circumference of the two bundles is the same, a section of the former is smaller, and contains less iron than a section of the latter. Therefore, if the two coils be connected with the same battery, the same quantity of electricity will flow through both; and the quantity of iron in the flat or elliptical one being less than in the cylindrical one, it will be more intensely magnetized.

I find that all cores consisting of bundles of parallel wires have five defects. First, in each section of every wire in such cores an electrical current is induced by the primary current, and all those currents may return to the points where they originated; or there is a complete circuit for them, which is found to diminish the intensity of the secondary current. Some have imagined that by insulating the wires of the core from each other, they have prevented all complete circuits. But these persons seem to have forgotten, or not to have adverted to the fact, that when the wires of the coil are insulated from each other, the primary current induces an electrical current in each section of every wire.

The second defect consists in this, that the currents induced in each section of every wire are opposed by those in the corresponding sections of all the adjoining wires; and thus the magnetic power which the primary current is capable of producing in the core is greatly diminished, and is less than it would be if all the wires were in close contact with each other; and consequently the intensity of the secondary current is diminished.

The third defect is, that the immense quantity of electricity set in motion by the primary current in all the sections of each wire in the core is lost: it remains within the core, and cannot be used for producing any electrical effect.

The fourth defect is, that we cannot ascertain the effect which a condenser applied to the primary coil has on these currents.

The fifth defect is, that we cannot apply a Leyden jar or any condenser to the currents themselves.

I have found that a core consisting of a coil of insulated or covered iron wire is free from all these defects. In such a core there is no complete circuit for any current in any section of the iron: for the electrical currents produced by the primary current in the sections of an enclosed iron coil move in the directions of the spirals of the coil; and since no spiral returns to itself, no current can return to the point where it originated. Neither does the current in any spiral of the coil oppose those in the adjoining spirals; for the currents in all the spirals flow in the same direction, or in the direction of the primary current. Thirdly, since all the currents in the spirals of the iron coil flow in the same direction from the beginning to the end of the coil, they must unite and form one current, having an intensity equal to the sum of their intensities. This I have proved by using a coil of very fine insulated iron wire, about 10,000 feet in length, as the core of a copper coil. When the connexion between the ends of the copper coil and a single cell was broken, sparks about one-twelfth of an inch passed between the ends of

the thin iron wire without using a condenser. Fourthly, by connecting the primary coil with a condenser, I have found that the intensity of the current in the core is increased as it is in the current of the secondary coil. Fifthly, by connecting the ends of the core or iron coil with a Leyden jar, the length of the spark is diminished and its brightness increased. The effect of the condenser on the currents in the core may assist us in understanding the action of the condenser, which has not yet been satisfactorily explained.

A core consisting of a coil of insulated iron wire, has not only the advantages of being free from the five defects to which all the cores in common use are subject, but it will also enable us to get electrical currents having at the same time great intensity and considerable quantity, and may therefore be very advantageous for working the Atlantic Telegraph, and for producing the electric light. If we make a core of thirty covered iron wires, each one-eighth of an inch thick and 100 feet long, and wind over the iron coil a covered copper wire one-fourth of an inch thick, we can, with the aid of two cells and a suitable condenser, obtain thirty electrical currents, each having a considerable quantity of electricity, because the wires are short and thick, and an intensity greater than that which is required for the electric light. Sixty covered iron wires, of the same length and thickness as those in the core, may be rolled on the copper coil. Another coil of copper wire, one-fourth of an inch thick, may be put over the second iron one, and over this copper coil we may wind sixty or eighty covered iron wires, each 100 feet long and one-eighth of an inch thick. Then the innermost iron coil will be the core of the first copper one; the second iron coil will be the secondary coil of the first copper coil, and the core of the second; the third iron coil will be the secondary coil of the second copper coil. If the copper wires be connected with a battery of six cells, each about 5 inches square, and a condenser of sufficient size, an enormous magnetic power will be given to the 150 or 170 wires of the iron coils; and consequently 150 or 170 electric currents of considerable quantity and intensity will be produced as often as the connexion between the copper wires and the battery is broken. If necessary, the number of iron coils, and therefore the number of electric currents, may be increased. Mr. Shephard has got a brilliant electric light from eighty electric currents produced in coils of copper wire on the armatures of permanent magnets. I think that 150 currents produced by the coil I have described would far exceed in quantity and intensity the eighty currents obtained from Mr. Shephard's machine.

The electric light may perhaps be produced by several coils, like the one I showed at the meeting of the Association, and

which has given sparks the $\frac{15}{16}$th of an inch, with one cell and without a condenser. The secondary coil is divided into four parts, each of which will give sparks about a quarter of an inch. I intend to make four or five other coils of equal power, and to divide the secondary coil of each into six or eight parts. The ends of the wire of each part will be left projecting from the coil. Thus in the five or six coils there will be between thirty and forty small secondary coils, each containing about 8000 or 10,000 feet of fine iron wire. Each of these secondary coils will give sparks at least one-eighth of an inch, with a battery of five or six cells and without a condenser. With a good condenser we may fairly expect that each will give sparks nearly 2 inches in length. Thus with a battery of five or six cells I think I shall have between thirty and forty currents, each capable of passing through about 2 inches of air. If the opposite ends of the thirty or forty small coils be connected with the opposite coatings of several large Leyden jars, and the sparks be passed between two coke-points, a brilliant light may be produced. Besides the coil which I have described, and which was divided into four parts, I made another which was 40 inches long, was divided into nine parts, and in which there were at least 70,000 feet of fine iron wire. Unfortunately, the secondary coil was seriously injured before I was able to make a single trial of its power. In dividing the two coils into several parts, I had three objects in view. First, to secure better insulation. The division of the secondary coil for the purpose of preventing the passage of sparks from one layer of the coil to the layer above or below it, was first recommended by Professor Poggendorff. Although this mode of preventing sparks within the coil occurred to myself before I saw his excellent paper on the induction apparatus, I was doubtful whether it would be of use, until I tried it in the last coil I made. My second object in dividing the secondary coil into parts, was to try the combined effect of the currents produced in each part by connecting the beginnings of all the parts with one coke-point, and all the ends with another. My third object was to try the effect of a Leyden jar connected with each part of the secondary wire, as well on the sparks produced by the part itself, as on the sparks produced by the whole secondary coil.

In order to get currents of considerable quantity, and at the same time of very great intensity, the core and secondary coil should be one continuous wire, about one-eighth of an inch thick, and the end of the core should be connected with the beginning of the secondary coil. I made a flat coil of covered iron wire one-eighth of an inch thick. The length of the coil was about 18 inches, its breadth 14, and its thickness between 4 and 5 inches.

The length of the wire was about 2000 feet. On this iron coil I wound 150 feet of copper wire nearly one-fourth of an inch thick. By connecting the ends of the copper wire with a battery of two or three 4-inch cells, and a condenser in which the surface of each plate was 400 square feet, sparks about the twentieth of an inch would be made to pass between the terminals of the iron core. I have reason to think that had the condenser been only one-third or one-fourth of the size, the sparks would have been longer. When the ends of the iron core were connected with a condenser in which the acting surface of each plate was about fifty square feet, and in which the plates were insulated from each other by waterproof gutta-percha cloth, the current passed from one plate of the condenser to the other as freely as if they were connected by a good conductor. When the terminals were connected with three large Leyden jars, the brightness of the spark was increased, whilst its length scarcely suffered any diminution. I intended, but had not time, to coil over the copper wire another iron one of great length, and the same thickness as the one in the core, and to unite both together. Had I been able to do so, the combined currents of the core and secondary coil would form one of enormous intensity and considerable quantity. Two coils of this kind, each having a bar of iron in the inner iron coil, and having the ends of the iron bars connected by iron armatures, in the same way as in Mr. Whitehouse's coils, would, I think, answer better than his for the Atlantic Telegraph.

It appears to me that Mr. Whitehouse's coils admit of three important improvements. First, they may be greatly improved in the core by substituting for his secondary coil of copper wire a coil of covered iron wire of the same length and thickness. The iron wire would be intensely magnetized by the primary current, and by the inductive magnetic power of the enclosed iron bar; and in losing its magnetism at the moment the battery connexion is broken, a current will be induced in it of far greater intensity than that of the secondary current in Mr. Whitehouse's coil. Mr. Whitehouse's object in connecting the ends of one core with the ends of another by iron armatures, is to prevent the rapid suspension of the magnetic power of the cores at the moment the connexion between the battery and primary coil is broken. By causing the cores to lose their magnetism gradually, a series of currents corresponding to the successive diminutions of magnetic power is induced in the secondary coil: this series of currents has the effect of a continuous current, which is found to be of use in working the telegraph. The same object may be attained by using a core consisting of an iron bar and a coil of insulated iron wire. The iron bars may be connected by

iron armatures extending over the ends of the iron coils, but separated from them by a piece of gutta-percha about the one-fortieth of an inch in thickness. Mr. Whitehouse's object might perhaps be attained still better by connecting the cores of every two coils, by six or seven, or a greater number of armatures. This may be done by brazing or otherwise fastening to the iron bar in each coil, plates of iron about a quarter or three-eighths of an inch thick, and sufficiently large to project an inch or two beyond the iron coil of the core. A small piece should be cut out of each plate, that the primary wire may pass from one side of the plate to the other. The corresponding plates fastened to the two iron bars may be connected by a plate of iron. Thus the two iron bars will have as many armatures as iron plates, and the magnetic power of the core will be retained longer than if there be only two armatures, and consequently the series of induced currents will continue for a longer time. Secondly, a great improvement may be made in the primary coil. Mr. Whitehouse's primary coil consists of twenty-four copper wires, No. 14, or about the $\frac{1}{11}$th of an inch thick, and 100 feet long. Now if the primary coil were made of copper wire of the same length, and nearly half an inch thick, it would conduct as much electricity as the twenty-four wires used by Mr. Whitehouse, and would produce greater magnetic power in the core, because the electricity flowing in the thick wire would be nearer to the core than the electricity flowing through the twenty-four thin wires. A third improvement may be made by winding over the primary coil an insulated iron or copper wire of the same length and thickness as the wire in the core, or of greater length, and uniting the end of the coil in the core with the beginning of the coil outside the primary coil. Such a coil would produce with a given battery a current of far greater intensity than that which would be produced by one of Mr. Whitehouse's coils, or a current of equal intensity with a much smaller battery. It appears to me, then, that the use of coils such as I have described would be greatly to the advantage of the Atlantic Company, or any company having a very long telegraphic line.

The fifth form of core which I used consisted partly of a coil of insulated iron wire, and partly of a bundle of iron wire. In one core of this form the iron wire of the coil was about the $\frac{1}{100}$dth of an inch, in another it was one-eighth of an inch thick. From the part of the core which consisted of iron wire $\frac{1}{100}$dth of an inch thick, I got sparks a quarter of an inch with a single cell and without a condenser. The length of wire in this coil was about 15,000 feet.

The sixth form of core which I used consisted of two concentric coils of insulated iron wire: one of very fine, the other of

thick wire. The coil of thick wire should be enclosed within the coil of fine wire, and should be nearly 2 or 3 inches in diameter, especially when the primary coil is made of thick wire. In making coils of thick iron wire, great care is necessary, for in such wire there are cracks or flaws. At these cracks there are sometimes sharp points, which cut the covering of a spiral in an adjoining layer, and thus make a complete circuit, which is most injurious to the intensity of all the currents induced in the various parts of the coil. It is necessary to know that the complete circuit which diminishes the intensity of the secondary current in the greatest degree, is that which is made by connecting the ends of a coil of thick wire. I have not had time to determine which of the forms of core I have used induces the most intense current in the secondary coil, or which of them makes the condenser act with the greatest effect. I once used for the core a bundle of wires, 9 inches in diameter and 26 inches long. The weight of the core exceeded two hundred and a half pounds. This core acted so badly, as to convince me that anyone who wishes to obtain currents of very great intensity, or very long sparks, should never employ cores of very large diameter.

The fourth result is an improved method of insulation for the secondary coil. In this mode the insulation is imperfect where imperfect insulation is sufficient, and perfect where such insulation is required, and consequently each spiral is brought nearer to the core, to the primary coil, and to the other spirals of the secondary coil, than in the ordinary manner of insulation, in which the parts of each layer for which very little insulation is required are as well insulated from the layer above and below it as the parts which require the best insulation. My mode of insulation differs from the ordinary one in two respects:—First, in the insulation of each spiral from the adjoining ones in the same layer; secondly, in the insulation of the spirals of every layer from the contiguous spirals of the layer above it. I do not cover the fine wire with thread of any kind; but I coat it with a very thin film of varnish by drawing it through melted rosin and bees-wax. I draw it through the hot varnish by winding it on the coil at the distance of about 25 feet from the stove by which the varnish is heated; I have found that at this distance the varnish is cool and hard, even when the wire is drawn through it at the rate of 8000 feet in the hour. Thus in this mode of insulating the fine wire, a coil may be made in a comparatively short time. The insulation is sufficient, because the difference between the intensity of any spiral and the adjoining ones of the same layer is indefinitely small. On every inch of each layer I can put eighty or eighty-two spirals of

wire $\frac{1}{100}$dth of an inch thick. My mode of insulating the spirals of each layer from those of the layer above or below it, differs also from the way in which they are insulated by others. In the common mode of insulation, if, as in Mr. Gassiot's great coil, five thicknesses of gutta-percha, or of any other insulating substance, be thought necessary in order to insulate the extreme spirals of any layer from those of the layer below it, five thicknesses of the insulating substance are put between the whole length of every two adjoining layers; so that if there be twenty layers along with the first, there will be 100 thicknesses of the insulating substance. But, in my mode of insulation, there would, in such a case, be only sixty. In order to render my mode of insulation intelligible, I shall explain how the first layer of spirals is insulated from the second, and the second from the third. Every other layer, such as the third, fifth, seventh, &c. represented by an odd number, will be insulated from the one above it, in the same way as the first is insulated from the second; and every layer, such as the fourth, sixth, eighth, &c. represented by an even number, will be insulated from the one above it, in the same way as the second is from the third. In insulating the first layer from the second, when five thicknesses of the insulating substance to be used are deemed necessary for the insulation of the last spirals of the second layer from the first spirals of the first (there the difference of intensity is greatest), I divide the length of the layer into five equal parts. I then put one thickness of the insulating substance (let us suppose it to be what I use, viz. the paper employed for copper-plate engravings saturated with a solution of gutta-percha in oil) on the entire length of the first layer, and then roll the fine wire on one fifth of the layer. I next cover the whole length of the coil with another thickness of prepared paper, and coil the fine wire on the second fifth of the layer. I then put on a third thickness of paper, and wind the wire on the third fifth of the coil. I then put on another thickness of paper, and coil the wire on the fourth fifth, and so on. Then between the first fifth of the second layer and the spirals below it in the first, there is one thickness of paper; and one will insulate them as well as five will insulate the whole length of the two layers from each other. Between the second fifth of the second layer and the part of the first layer below it, there are two thicknesses of paper, and they will sufficiently insulate these two parts from each other. In the same way the third is insulated by three thicknesses, the fourth by four, and the last by five thicknesses of paper: thus the five parts of the coil are as well insulated from each other as if there were five thicknesses between the entire length of the two layers. To insulate the second layer from the third, as well

as the first is insulated from the second, only one thickness of paper is necessary; for by putting a single thickness of paper on the second layer, the first fifth is covered by one, the second by two, the third by three, the fourth by four, and the last by five thicknesses of paper. Hence to insulate any two layers, only six thicknesses of the insulating substance are necessary, or three for the insulation of each layer; and therefore to insulate twenty layers, only sixty thicknesses of the insulating substance to be used are required. Thus in my mode of insulation, every spiral in the secondary coil is brought nearer to all the contiguous spirals and to the primary coil and core, than in the ordinary method of insulation; and consequently the inductive power of the core and of the primary coil on the secondary one, as well as the inductive power of the spirals of the secondary coil on each other, must produce a secondary current of far greater intensity in mine than in the common mode of insulation. The coil which was shown at the meeting of the British Association was insulated in the manner just explained. This coil and the contact-breaker, which will be presently described, were seen at work by Mr. Gassiot, Dr. Robinson, M. Foucault, Professor Rogers, and other members of the Association. Mr. Gassiot was so much pleased with their action and construction, that he ordered from Mr. Yeates, an optician in Dublin, a contact-breaker and two secondary coils like mine. In each of these secondary coils there will be nearly 60,000 feet of iron wire about the $\frac{1}{100}$dth of an inch thick.

The fifth result is a contact-breaker in which the striking parts are copper, and which act as well as if they were platina. The contact breaker consists, first, of a small electro-magnet; secondly, of its armature screwed to a board moveable on a hinge, and having attached to it a spring connected with the vibrating piece of copper; thirdly, of a spring for pressing the striking pieces together; and of a trough containing oil, in which these pieces are always immersed. By means of the spring attached to the board to which the armature is fastened, the armature is brought within the most convenient distance from the small electro-magnet. The spring presses the striking pieces together with the greatest force the electro-magnet is capable of overcoming, and the pressure is exerted immediately over the points of contact. The oil prevents in some measure the oxidation of the copper, and serves to stop the battery current more quickly; for as soon as the pieces of copper are separated, the oil rushes in between them, and being a non-conductor, instantly stops the galvanic current from the battery. In the first contact-breaker which I made of this kind, there were two vibrating pieces, one of platina, the other of copper; the former struck against

another piece of platina, the latter against a piece of copper: the copper was immersed in oil. By means of two screws, both might be made to make and break contact together, or I could cause either to make and break contact. By first causing the platina, and afterwards the copper, to make and break contact, I found that the copper acted as well as the platina. In the contact-breaker which I showed at the meeting in Dublin, there were three vibrating pieces of copper, each about three-eighths of an inch thick. M. Foucault thinks that the contact will be made and broken as well by one as by several vibrating pieces. Though that should be the case, the addition of two other pieces will not be useless; for the three may be immersed in different fluids, and thus we can discover the fluid in which contact may be made and broken with the greatest advantage.

The sixth result is a more satisfactory explanation of the condenser. In order to understand the action of the condenser, we must examine the electrical state of the primary coil at the moment its connexion with the battery is broken, and the effect which this state has on the core and secondary current. At the moment the connexion between the battery and primary coil is broken, the electricity which it received from the battery continues to flow to the end of the coil to which it was moving; but being no longer urged forward by the battery, its velocity is constantly diminished by the resistance of the wire. This electricity moving more slowly than when the coil and battery were connected, and in the same direction as the battery current, is not able to maintain in the core, or in the primary or secondary coil, the magnetic power produced in them by the battery; but it maintains a part of it, and prevents the core, the primary and secondary coil, from losing their magnetism in an instant, and consequently diminishes the intensity of the secondary current. The condenser prevents the gradual diminution of the velocity of the electricity flowing in the primary coil at the moment its connexion with the battery is broken, and probably accelerates it; for in an instant after the battery connexion is broken, the end of the coil towards which the electricity is moving, and the plate of the condenser connected with it, become positive. This positive plate instantly renders the other plate negative: the latter then attracts electricity to the former with an enormous force, on account of their very close proximity; and if the plates of the condenser be of sufficient size, the electricity moving in the primary coil will be drawn with such force to the positive plate, that its velocity, instead of being diminished, will probably be increased. Thus the condenser removes the obstacle arising from the electrical state of the primary coil, to the

sudden suspension of the magnetism of the core, and of the primary and secondary coil, and probably increases their magnetic power by accelerating the current in the primary coil after its connexion with the battery is broken. The condenser not only removes an obstacle to the instantaneous suspension of the magnetism of the core and of the primary and secondary coil, but it also supplies a force tending to destroy that magnetism; for as soon as all the electricity moving in the primary coil is drawn to the positive plate of the condenser, it instantly rushes back to the negative one through the primary coil, and is drawn to itself by that plate with an immense force; and in its passage through the primary coil, tends to reverse the magnetic poles of the core of the primary and secondary coil, and consequently to destroy their magnetism. Hence the effect of the condenser is to make the core, the primary and secondary coil, lose their magnetism instantaneously, and thus to increase the intensity of the secondary current, or the length of the sparks produced by that current. This explanation of the action of the condenser is confirmed by the effect which I have found it to produce on the electrical currents induced by the primary current in each section of the core, viz. an increase of their intensity. Now the only causes that can produce an increase of intensity in these currents are, an increase of the magnetism of the core, and of the rapidity with which it loses its magnetic power, or either of these two causes. I have shown that the effect of the condenser is at least to increase the rapidity with which the core loses its magnetism, and probably to increase its magnetic power. Hence my explanation of the action of the condenser is confirmed by the effect of the condenser on the currents produced in each section of the core.

The principle of this explanation of the action of the condenser suggested to me a new form of condenser, which I expected would act more powerfully than the condenser now in use. The new condenser was to consist, not of sheets of tinfoil, but of a large number of very thin sheets of iron, arranged in such a way that one-half of them would form one plate, and the other half the other plate of the condenser; and that the electrical current by which each plate would be charged, one positively, the other negatively, should not enter simultaneously each of the iron sheets forming the positive plate, nor leave simultaneously all the iron sheets in the negative one, but should flow through the whole length of each sheet, before entering into the next. In order to make a condenser of this kind, I got 112 sheets of iron, each 28 inches long, 10 broad, and about $\frac{1}{80}$th of an inch thick. I intended to arrange them so that the current by which they would be charged, at the moment the connexion between the primary coil and battery would be broken, should flow successively

through the whole length of the 112 iron sheets, or through one plate equal in length to the sum of their lengths, which exceeds 250 feet. Had I had time to make, as I intended, our iron condenser in this way, the iron plates would be strongly magnetized by the electrical current flowing through their entire length; and in losing their magnetism, would produce a powerful secondary current, tending to destroy or to reverse the magnetism of the core, and thus increase the intensity of the secondary current. In the ordinary condenser there is one electrical current tending to destroy the magnetism of the core: in an iron condenser made as I have described, there are two currents tending to produce the same effect; viz. the current arising from the rush of electricity from the positive to the negative plate of the condenser, and the current caused by the demagnetization of the iron plates. In order to save time and trouble, I made our iron condenser in the ordinary way. When I have leisure I may make it in the manner I have just described.

The seventh result consists in the discovery of some new facts regarding the condenser, which have not been hitherto noticed in any publication. First, I have found that the action of the condenser is feeble when the core is a solid bar of iron; secondly, when it is a coil of fine insulated iron wire not having a bundle of iron wire, or a coil of thick covered iron wire in the hollow part of it; thirdly, when the quantity of iron in the core is very great compared with the thickness of the primary wire. Secondly, I have found that the size of the condenser must be increased with the conducting power of the primary wire. Thus a thick primary wire requires a larger condenser than a thin one; a primary wire of copper requires a far larger condenser than one of iron of the same length and thickness; and a very short primary wire of any metal requires a condenser very much larger than that which is necessary for one of the same metal 100 feet long. I have found that when the primary wire is not more than 30 feet, a condenser of moderate size will not produce the slightest effect on it. Thirdly, I have found that when a condenser is very much larger than that which is required to produce the full effect of a condenser on a given coil, it not only does not increase the power of the coil, but it makes it less than it would be without a condenser, and sometimes destroys it; and that in general there is a limit to the size of the condenser, beyond which its effect on the coil will be diminished. Fourthly, I have found that a condenser so large as to diminish the power of a coil excited by one cell, will increase its power when the coil is excited by ten or twelve cells. Hence the same condenser will not answer for the same coil when batteries of very unequal powers are used. Then, every

condenser should be made in such a way that the entire of it will produce the full effect of a condenser on the coil for which it is intended when the largest battery we wish to use is employed, and that a small or a large part of the condenser may be used when we wish to excite the coil by a weak or strong battery. I learned from Mr. Gassiot and M. Foucault during the late meeting of the Association, that they were aware of the necessity of making the condenser in this way.

Maynooth College,
Sept. 29, 1857.

P.S. I have abstained from saying anything about the primary coil, because my experiments on it have not led me to a satisfactory conclusion, and not because I think the primary coils in common use incapable of improvement. I believe that they are very badly calculated to attain their object, and that they have been made on a false principle.